Chapter 8 The Moon and Mercury

Orbital Properties

We are going to begin our study of the Moon and Mercury by looking at their orbits which will then help explain other characteristics of these bodies.

The Moon

By using radar methods we have determined the distance to the Moon. It takes 2.56 seconds for a pulse to go there and back. If we divide this by 2 and then multiply it by 300,000 km/sec we find that the Moon is about 384,000 km from the Earth. The actual distance at any one time is determined on where the Moon is due to the fact that the orbit is an ellipse. Now we can fire a laser to the Moon and bounce it off some reflectors left on the Moon and get a submillisecond time to measure the distance. We use this kind of accuracy to program unmanned satellites so that they will land successfully on the Moon.

Mercury

From Earth, we never see Mercury very far from the Sun. It is about .4 AU from the Sun so we never see it more than about 28° from the Sun. The only time we can see the planet is just before sunrise or just after sunset. Since we rotate at 15° per hour, we should be able to see Mercury for almost 2 hours. But that is not usually the case. Since we don't always see Mercury when it is at it's farthest, we usually see Mercury for much less time. Modern telescopes now have ways to block out the Sun so that it can bee observed during the day. The best images of Mercury have come when it is at it's farthest from the Sun which is called *maximum elongation*.

Physical Properties

The angular size of the Moon is about .5° and since we know how far away it is we can determine the radius of the Moon. The most accurate measurement of the Moon's radius is 1738 km. We can measure the size of Mercury in a similar fashion. We get a radius of about 2450 km. Satellite measurements of Mercury reveal a radius of 2440 km.

The Moon's average density is about 3300 kg/m^3 which means that it is made up of lighter material and has no heavy metallic elements. Mercury's density works out to be about 5400 kg/m^3 which says that there is a high level of metallic elements.

Since the Moon and Mercury are so much smaller than the Earth these 2 bodies have a much smaller gravitational field. The gravity on the Moon is $1/6^{th}$ of the Earth's and on Mercury it is 40% of the Earth's gravity. Go to either one of these and you would weigh much less than you do here.

There is no appreciable atmosphere on either one of these bodies. This is a consequence of their weak gravities. The escape velocity on the Earth is 11.2 km/sec, while on the Moon it is 2.4 km/sec and on Mercury it is 4.2 km/sec. There are atoms of gas on both bodies, but it is a trillionth of the Earth's atmosphere. This means that both of these bodies are at the mercy of the harsh climate of space. On both of these bodies the temperature is quite harsh. On the Sun side the temperature on the Moon at noon can reach 400 K and on Mercury it can reach 700 K. On the night side, since there is no atmosphere to hold in the heat, the temperature will drop to 100 K. This 600 K drop is the largest in the solar system.

Surface Features on the Moon and Mercury

When Galileo first turned his telescope to the Moon one of the things he saw were large dark areas. He called these areas *maria* which is Latin for seas. Today we know that these are actually flat lava flows on the Moon. There are 14 maria on the Moon and most of them are circular in shape. Mare Imbrium is about 1100 km in diameter. The maria are actually impact craters on the Moon. The lighter part of the Moon was originally called *terre* which means land. Since they are elevated over the maria they are now called the *highlands*. The smallest feature that we can see naked eye on the Moon is about 200 km across. When you look through a telescope you will see that there are many *craters* of various sizes. Most of these formed eons ago due to a meteor impact. When looking at the Moon craters are especially prominent when they are along the terminator or the shadow line on the Moon. Due to our atmosphere the smallest lunar object we can see through a telescope is about 1 km.

Rocks that have been brought back by Apollo and unmanned Russian spacecraft have shown that there is a big difference in age and composition between rocks in the maria and the highlands. The highland rocks are richer in aluminum and have a density of 2900 kg/m^3 while the dark maria rocks are richer in iron and have a density of $3300kg/m^3$. Basically the highlands are the lunar crust while the maria is the mantle material. The highland age is between 4.1 – 4.4 billion years old while the maria is between 3.2 – 3.9 billion years old. All of the prominent features on the Moon have names. The craters are named after great scientists. One of the things that you will notice is that the Moon rotates in the same time that it takes to orbit the Earth. This means that only one side of the Moon faces us and from the Earth you and I have never seen the other side. The backside contains almost exclusively highlands. This helps prove that the Earth must have had some influence in how our side of the Moon formed.

The Surface of Mercury

Seeing the surface of Mercury is difficult from Earth. It is close to the Sun, it is small, and we are looking through our atmosphere. In 1974 Mariner 10 came within 10,000 km of Mercury and sent back over 9000 pictures. We could see objects as small as 150 m across. This was fantastic. Mariner 10 was put into orbit around the Sun, not Mercury, and came by every 176 days, exactly 2 Mercury years. But this led to the fact that we only saw one side of Mercury. That means we have mapped less than half of Mercury. The views of Mercury are very similar to the Moon's surface.

Rotation Rates: The Rotation of the Moon

We have never seen the back side of the Moon except by satellite or Apollo. The Moon's rate of rotation is exactly the same as its orbit. This is 27.3 days. When you have an orbit like this it is called a *synchronous orbit*. As we talked about in the previous chapter, the Moon is slowing down the rotation of the Earth. This is exactly what happened to the Moon. The Earths gravity slowed it down until only the one side faces us. It has become *tidally locked*.

Measurement of Mercury's Spin

Originally it was thought that Mercury was like the Moon with one side facing the Sun. That meant that the rotation rate was every 88 days. In 1965 from Arecibo, Puerto Rico

they used the radio telescope to bounce radio waves off Mercury. It was found that waves coming from the edges of Mercury were changed due to the Doppler shift and this could be measured. From there it was determined that Mercury rotated every 59 days. This is exactly 2/3's of the revolution around the Sun. So for every 3 rotations there are 2 orbits. This is called a *spin-orbit resonance*. Resonance simply means that the 2 are related to each other in a simple way.

Explanation of Mercury's Rotation

The 3:2 spin-orbit resonances didn't occur by chance. Tidal forces due to the Sun's gravity are responsible in a very subtle way. Tidal forces try to synchronize the rotation rate with the instantaneous orbital speed. But tidal forces decrease with distance, so the perihelion distance won out. At perihelion the rotation rate and orbital speed is the same, but not so at other points, so you end up with this 3:2 spin-orbit resonance. The Sun's influence also causes the axis to be perpendicular to the orbit which means that some parts of Mercury get much hotter than others. They are referred to as the *hot longitudes*. They will get to 700 K when the Sun is overhead. At the warm longitudes, where the Sun is overhead at aphelion, the temperature will only reach 550 K.

Lunar Cratering and Surface Composition

One of the big differences between the Earth and the Moon is that much of our surface has been eroded and things such as craters and other features have been lost to us. Not so on the Moon. Since there is no wind or water on the Moon, it doesn't experience erosion, so we can see it history in plain view.

Meteoric Impacts

On the surface of the Moon the major cause of change is the *meteoroids*. The Moon is covered in craters. On the Earth *meteors* burn up in the atmosphere. They are also called *shooting stars*. The Moon has no protection so large and small meteoroids come zooming in. Even as we talk, the Moon is still being hit by these pieces of rock and metal. Even small meteoroids that strike the Moon release large amounts of energy. A one kg piece of rock striking the Moon at 10 km/sec will release the energy in 10 kg of TNT. The crater formed is usually 10 times the size of the impactor. The typical depth is twice the meteoroids diameter. The area around the crater is shocked by the impact. There is material lying around the crater called the *ejecta blanket*. The Moon is also bombarded by micrometeoroids, or very small impactors. As you can see there are many more small craters on the Moon than there are large ones. Large impactors are rare while small ones are plentiful. For example, a 10 km crater forms about every 10 million years, while a meter sized crater forms every month, and a centimeter sized crater forms every few minutes.

Cratering History of the Moon

By dating the rocks that were brought back by the Apollo astronauts we realize that there was a period of intense bombardment about 4 billion years ago. It is thought that the entire inner solar system was subjected to this bombardment until about 3.9 billion years ago. The highlands on the Moon had solidified and we see the results of this. The maria solidified much later so we see only the impacts that occurred after it became hard. It is

thought that the maria are impact basins that formed at the end of this era of bombardment. After the impact, they filled with volcanic material. Orientale Basin formed at the end of this period, but it never filled with lava, so it is not a mare. There are several of these on the backside of the Moon. By counting the craters that are visible, we can determine the age of the body.

Lunar Dust

The surface of the Moon is covered with a layer of fine dust or *regolith* down to a depth of 20 m. On the maria it is only 10 m deep while in the highlands it may reach depths of up to 100 m. Scientists studying the craters on the Moon realize that there is a shortage of craters less than 20 m in size. They determined that they have been filled in by this dust. The rate of fill is about 5m per billion years.

Lunar Ice?

From the material that has been returned to the Earth, we see that the Moon is bone dry. But there does appear to be areas that may contain ice. Even back in the 1960's scientists thought that ice could exist at the lunar poles. They never exceed about 100 K or -173° C you could find permanent ice there. The Clemintine spacecraft in 1996 did radar mapping of the Moon and in a south lunar crater reported that it contained a low density material which is thought to be ice. The total could be in the trillions of tons of ice. The Lunar Prospector looked for hydrogen and found a large deposit which is taken to be tied up in water. Lunar ice remains a strong possibility, but not a fact yet. If it is there it is thought that it came from comets that struck the Moon. If it is there it is important because we can use the hydrogen for fuel and the water for survival. It costs between $2000 and $20,000 per kilogram to transport water to the Moon.

Lunar Volcanism

There are many examples of lunar volcanism on the Moon. There are *rilles* which are channels where molten lava once flowed. The maria are full of lava due to volcanism. All of the volcanism appears to have ended more than 3 billion years ago. This means that the surface has been dormant since then.

The Surface of Mercury

Like the Moon, the surface of Mercury is covered by craters, but not quite so many. In fact there are *intercrater plains* on Mercury. One possible reason is that older craters filled in with lava. One feature that Mercury has that the Moon doesn't have are the *scarps* or cliffs. These scarps cut across craters which tells scientists that what probably happened was shrinking of the planet. The interior cooled and shrank and the planet wrinkled. One of the last impactors is thought to have formed what is called Caloris Basin. The interesting fact here is that on exactly the opposite side of Mercury the terrain is oddly rippled and wavy. It is believed that the impact sent shock waves through Mercury and caused these features.

Interiors

The Moon

There is no evidence of any large scale magnetic field. There are some very weak fields that are associated with impact craters, but nothing due to the core of the Moon. After much study, it is thought that the Moon may have a very small iron core and that it is probably solidified. There are arguments about that. The lunar backside crust is thicker than the nearside which explains why the nearside has the maria and we find none on the backside. The Earth's gravity pulled the mantle closer to the Earth and this is why it is that way.

Mercury

A magnetic field about $1/100^{th}$ of the Earths was discovered at Mercury. It was thought that there wouldn't be any like on the Moon. Why is it there? It rotates too slowly to produce one and it may lack a liquid core to produce one, so why is it there? There is no real explanation. It may be the remnants of an extinct dynamo that would have caused the magnetic field. Never the less Mercury has a magnetic field that deflects the solar wind. The high density of Mercury indicates that it must be about 60% iron in composition.

The Origin of the Moon

There are several theories about the origin of the Moon. They are:

1) Sister Theory-the Moon formed at the same time as the Earth
2) Capture Theory-Earth's gravity captured a wandering body that came by
3) Fission Theory-the Moon split from the Earth while it rotated
4) Large Impact Theory-a Mars sized body struck the Earth and knocked off part of the Earth. Most widely accepted. Page 223

Evolutionary History of the Moon and Mercury

The Moon is about 4.6 billion years old and it underwent a massive bombardment during its first half billion years. This would have formed the surface as it is. The major cratering seems to have dropped off about 3.9 billion years ago and at about 3.2 billion years ago the impact craters filled in to become the maria. Due to its small size the interior of the Moon would have cooled off much more rapidly than a larger body.

Mercury

Like the Moon, Mercury has been dead for about 4 billion years. It contains little of the lighter material which is a result of being so close to the Sun. Being larger, it cooled slower and many craters were covered up by lava which is abundant on Mercury. As the core cooled and the crust shrank, not only did it form the scarps, but it may have squeezed shut the cracks and fissures that would have shut off the volcanic action.